Lessons learned during cryogenic optical testing of the Advanced Mirror System Demonstrators (AMSDs)

James B. Hadaway, Patrick J. Reardon, Joseph M. Geary, & Brian M. Robinson

The University of Alabama in Huntsville

H. Philip Stahl, Ron Eng, & Jeff Kegley

Marshall Space Flight Center

September 16, 2003

Outline

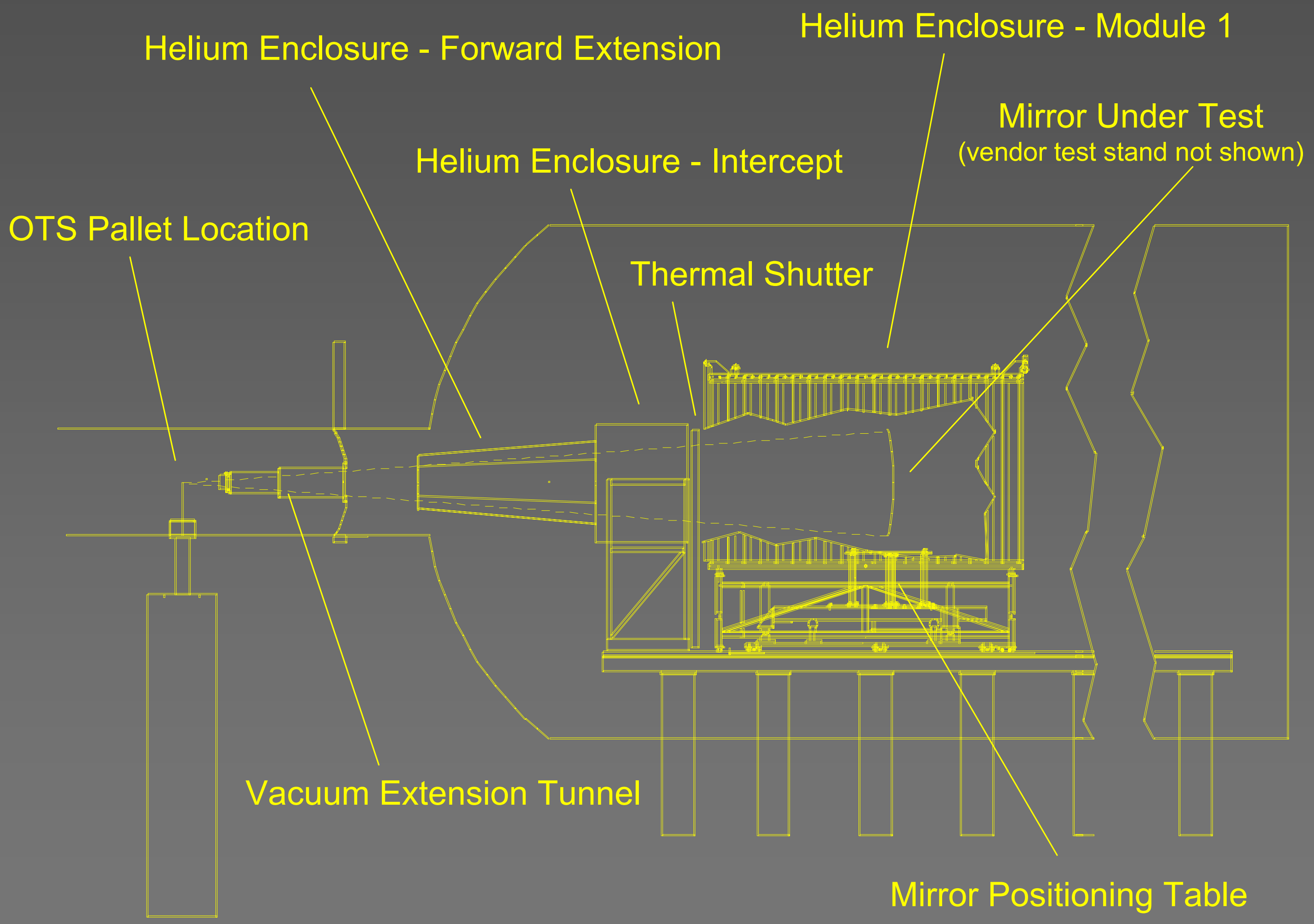
- AMSD Background
- Baseline Test Plan
- Lessons Learned During Planning & Preparation
- Lessons Learned During Testing
- Lessons Learned During Data Reduction & Analysis
- Summary

AMSD Background

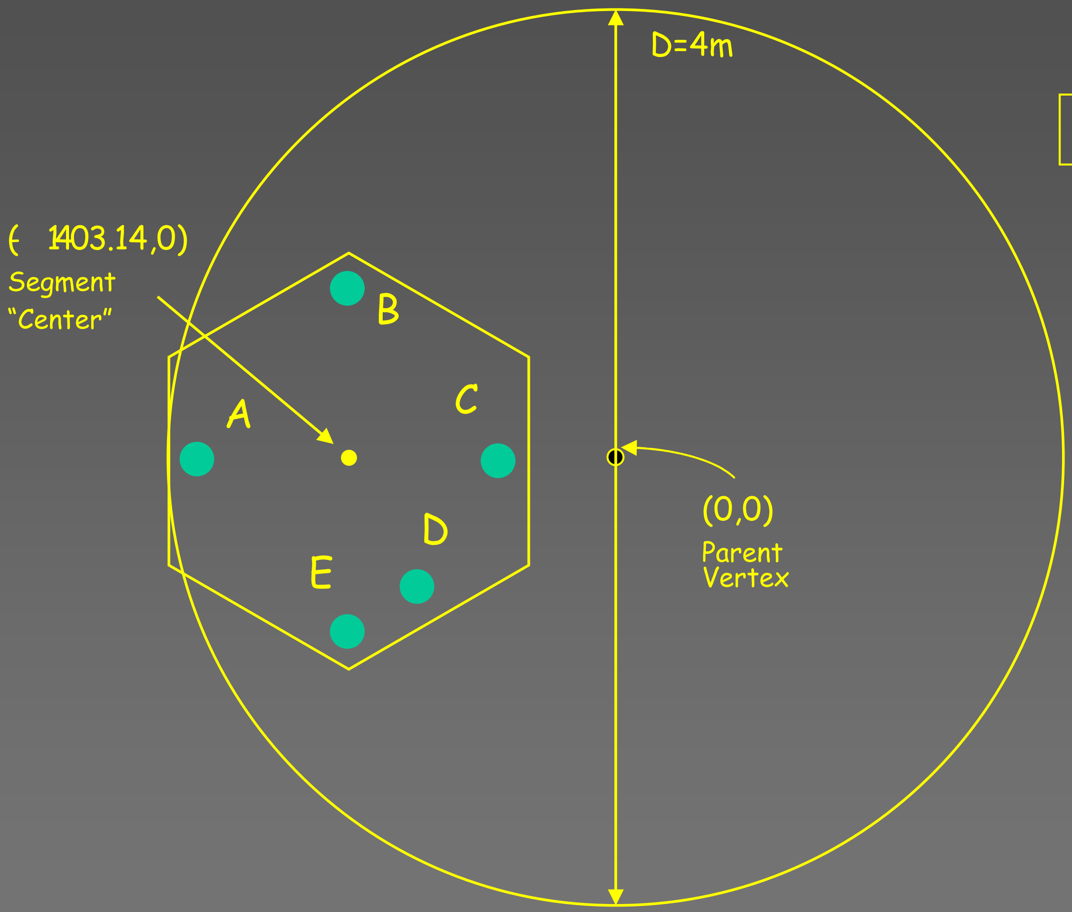
Final AMSDs <20 kg/m^2, 1.4 m diameter (pt-pt), hexagonal, off-axis parabolas with RoC = 10 m. Mirror performance requirements/goals at 35 K given below.

	Requirement	Goal
Total Figure, PV	250 nm (λ/2.5)	100 nm (λ/6.3)
Total Figure, rms	50 nm (λ/13)	25 nm (λ/25)
ROC, absolute	± 1 mm	NA
ROC, adjustability	± 20 μm	NA

AMSD Cryo Test Layout



AMSD Test Orientation

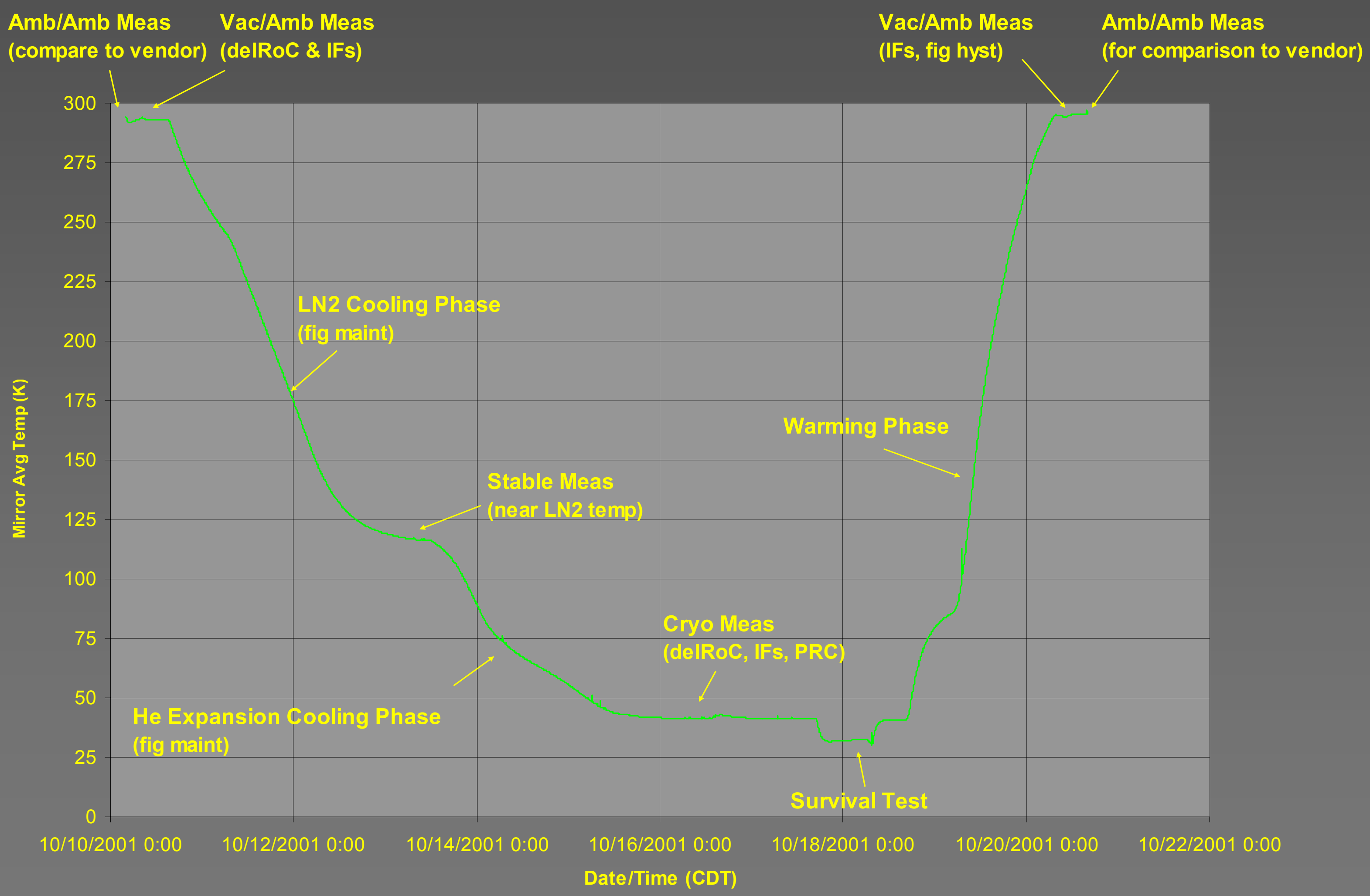


Fid Diam = 10 mm

Fid Locations (parent cords):
A = (-1900,0)
B = (-1393,550)
C = (-886,0)
D = (-1155,-412)
E = (-1393,-550)

AMSD as Viewed from Interferometer (interf looking at segment "center")

Typical Cryo-Test Cycle

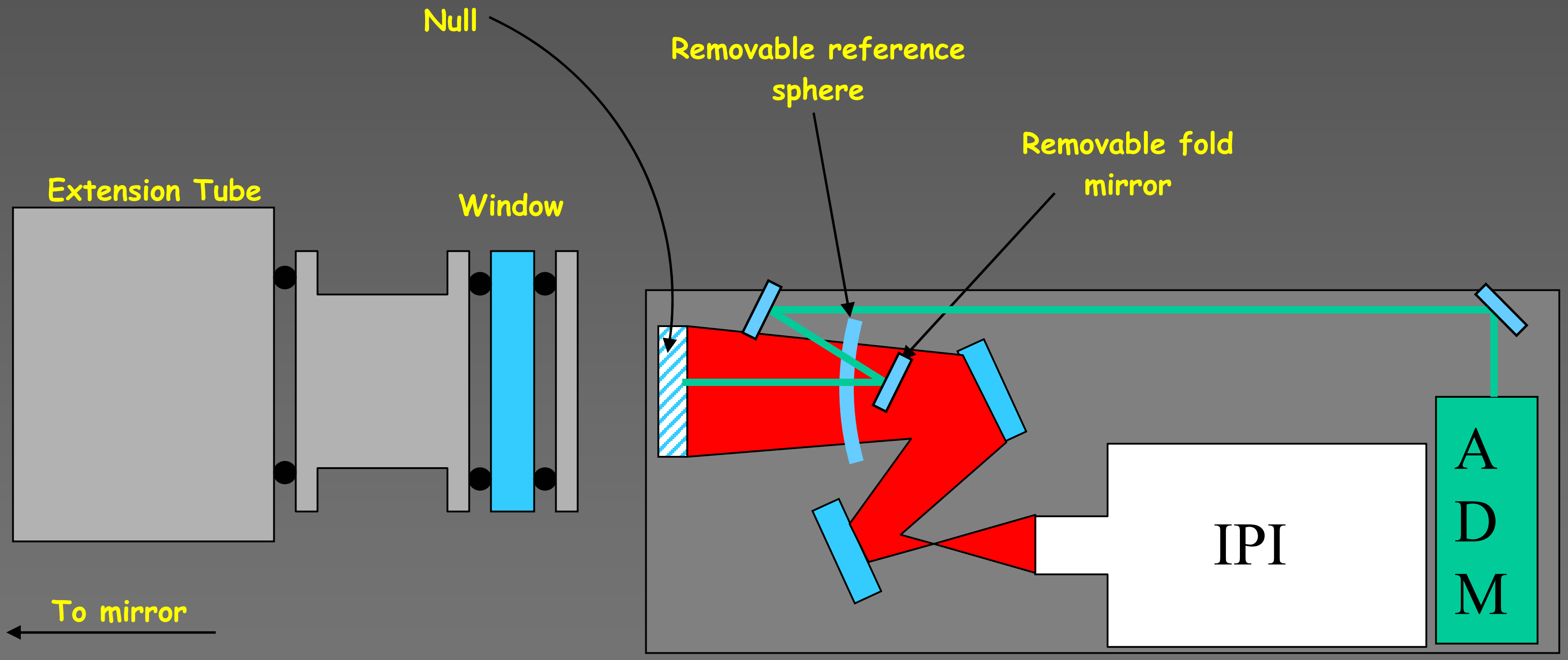


Measurement System

- Instantaneous Phase Interferometer or IPI (ADE Phase Shift):
  - Spatial carrier technique, 1Kx1K CCD, 0.125 msec shutter speed, surface accuracy ~3 nm RMS (w/ ref sub), OptiCode software, F/5 diverger.
- CGH System (Diffraction International):
  - Alignment CGH: Coarse align IPI/CGH to AMSD (spot projection).
  - Null CGH: Phase-only binary null; annular features to monitor CGH to IPI alignment, tests off-axis AMSD "on-axis".
- Absolute Distance Meter or ADM (Leica):
  - Polarization-based instrument developed from Laser Tracker.
  - Used to measure Null-to-AMSD distance (used for both figure & RoC) with uncertainty of ~20 um.
- Chamber Window:
  - 15.9 mm thick BK7, 147 mm CA, AR-coated for HeNe.

Measurement System Layout

1.5'x4' pallet supported by 6-DOF Hexapod (±2 um & ±10 urad repeatability) & coarse focus stage.



AMSD supported by 6-DOF motion table (±10 um & ±20 urad resolution).

Baseline Figure Measurement Method

- Must separate misfigure from misalignment.
- Use of traditional alignment fixtures/instruments mechanically attached to mirror problematic in this case.
- Baseline mirror alignment method based on work by Dente, Young, & Stahl.
  - Zernikes linearly-dependent on misalignment for both misaligned parabola with misfigure & misaligned perfect parabola (slopes same).
  - Minimize difference between measurement (contains misfigure & misalignment) and misaligned parabola with linear misalignment magnitudes as optimization variables (tilt set to align return to source for any misalignment).
  - Method used measured, not analytical, slopes.
- Total estimated surface figure measurement uncertainty estimated to be 14 nm-rms.
- Due to higher-than-expected low-order distortions at cryo, had to change to a fiducial-based alignment approach, leading to uncertainty of between 30 & 50 nm-rms (depending on number of mirror fiducials).

Lessons Learned During Planning & Preparation

- Maintain CONSTANT communication with the mirror manufacturing team.
- Dot all i's & cross all t's BEFORE the test starts (test req's, test plans, test proc's, data archiving & distribution plans/system).
- Characterize/check-out hardware & systems AS THEY WILL BE USED during the test.
- If a system characterization/check-out optic is not practical, allow 2X time for first test (really!).
- Your intuition and, probably, your models about how things will behave at 35 K are probably wrong.
  - Don't just model the nominal case.
  - Don't expect the properties of your materials to be uniform or constant.
- Use Murphy's Law as your guide & plan accordingly.

Lessons Learned During Testing (big picture stuff)

- Changing the goals of the test during testing is, in general, NOT wise.
- For light-weight mirrors, MEASURED gravity deformation is better than modeled.
- Have more than one alignment approach fully developed.
- A cryo figure measurement is NOT the same as an in-process measurement at ambient temperature (i.e. don't assume small figure errors).
- Be VERY careful regarding changes to test hardware/systems during testing.
- You CAN'T make up schedule lost during design & manufacturing in the testing phase.

Lessons Learned During Testing (detail stuff)

- More fiducials (on both mirror & null) solve many problems.
- CGH Null Issues:
  - Beware of pupil focus issues with CGH nulls.
  - Measured pupil distortion is better than modeled.
  - CGH mounting repeatability during an actual cryo test (over months) is not nearly as good as may be indicated by an hour-long, table-top repeatability test.
    - Avoid having to remove/replace the CGH on a regular basis.
    - Alignment features integrated into the null CGH, although difficult, are probably worth the effort.
- Mirror edges can be hard to find.
  - Plan for a careful edge-finding phase.
  - Be mindful of high slope and pupil focus effects.
- Your mathematical worksheets have errors in them, so don't blame the hardware.
- Follow the procedure.

Lessons Learned During Data Reduction & Analysis

- Short-cuts are hardly ever short.
- Data reduction/analysis ALWAYS takes longer than you thought (if done right).
- It's best to split the data reduction job from the data taking job (but not too far).
- Don't give up *measurement* accuracy/repeatability during *data processing*.
- Modeling doesn't stop when the test starts.
- The design & manufacturing teams know more about why the mirror did what it did than they realize.

Summary

- Keeping a running list of lessons learned is critical.
- The knowledge gained during this early cryo testing of ultra-lightweight mirror systems will be invaluable during the manufacturing & testing of the JWST flight mirrors.
- There is no substitute for experience.
- Remember, testing is fun!

Contacts

hadawayj@email.uah.edu

H.P.Stahl@nasa.gov